SMART SLEEVE DEMONSTRATION

PRESENTED AT THE DARPA TECHNOLOGY INTERCHANGE MEETING

Omni Inner Harbor Hotel

June 26-28, 2000

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Org. L9-21, Building 204

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Work supported by DARPA/ONR under Contract # N00014-97-C-0269

Dr. Ephrahim Garcia, DARPA Program Manager, Dr. Kam Ng, ONR COTR

S2D GOALS AND ROADMAP

Develop Cancellation Capability for Self and Radiated Noise from a Torpedo using the Smart Skin Integrated Systems Approach Demonstrated in the CSM Program.

Design, Build and Demonstrate Smart Skin on partial Mk 48 torpedo body

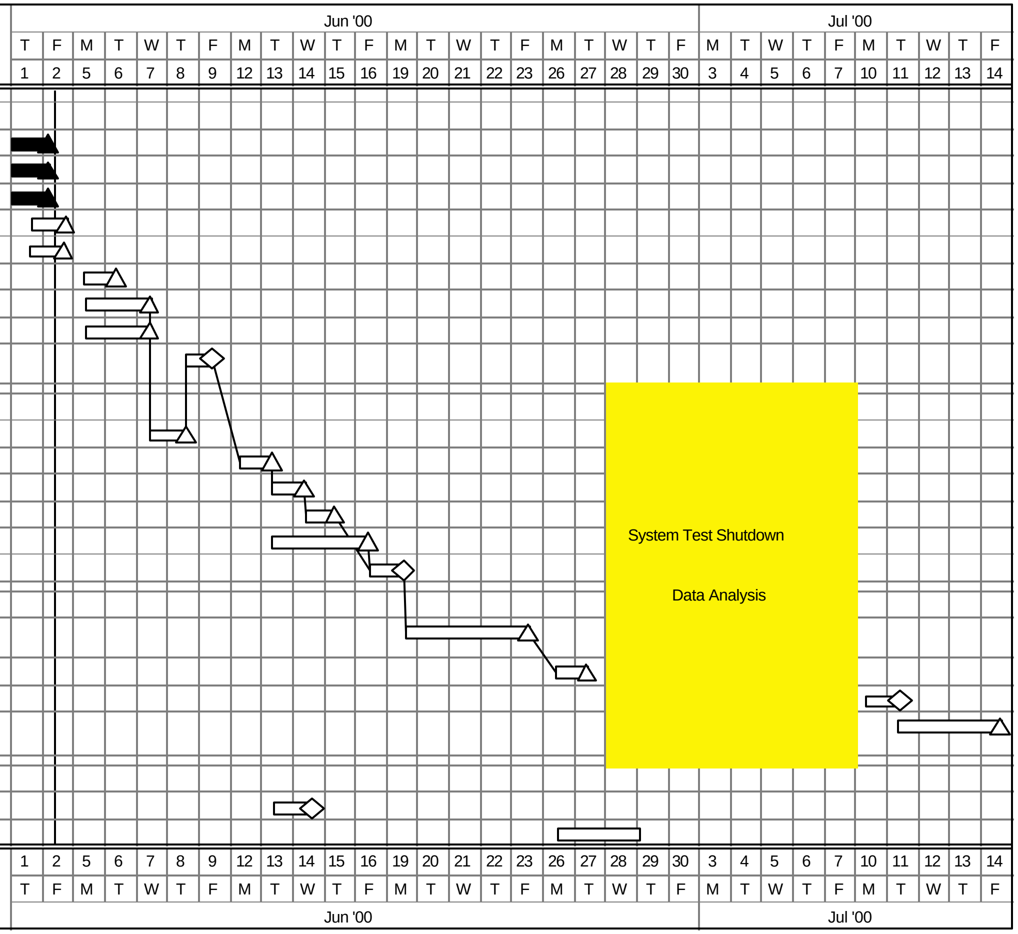
Refine the CSM tile design and add capability to cancel self and radiated noise. Improve manufacturability, further miniaturize components, lower cost, and demonstrate on 21" hull.

1997	1998	1999	2000
System Reqmt. Definition	**System Design Component Fabrication**	**Single Channel Test**	**Full Sleeve Test**

PROGRAM SCHEDULE, REMAINING TASKS

SMART SLEEVE DEMONSTRATION (S2D) - INTEGRATION PLAN DETAIL (June 1, 2000)

Activity Name	Personnel
2.3.3 System Integration	
Complete line drivers	EP
Install resistors on cable	JL, TW
Complete breakout box	TW
Complete F, a sig cond	EP
Replace faulty ref sensors	JL
Reconfigure damping plate	JL
Complete supply volt cable	JL/TW/EP
Install actuators & amps	JL
Integrate with controller & DAS	SSC, PD, JL, TW
2.3.4 System Checkout	
Checkout system continuity	TW, JL
Check analog subsys. resp. to control.	SSC, EP
Troubleshoot/retest analog resp. as req.	SSC, EP
Power flow test	SSC, CF,EP
Assemble surface cables & seal	TW,JL
Dunk in water / leak test	JL, EP
2.4.1 System Test	
First round of testing	SSC, RD, PD, EP
Haul out and stow	JL, EP
Dunk in water / leak test	JL, EP
Second round of testing	SSC, RD, PD, EP
2.2.6 Reviews and Reports	
Test plan & readiness review	
DARPA TIM	



TEAM MEMBERS AND ROLES

LOCKHEED MARTIN MISSILES & SPACE, ADVANCED TECHNOLOGY CENTER: Prime Contractor, System Design and Integration, Actuator Fabrication. **Steve Winzer (PM), Peter Dean, Kris Lauraitis, Ramji Digumarthi, Les Fisher, Ira Chapman**

ACTIVE SIGNAL TECHNOLOGIES: Actuator Design, Hardware System Integration and Test. **Keith Bridger, Ed Passaro, Joe Lutian, John Sewell, Terry Waskey**

SIGNAL SYSTEMS CORP.: Controls design, algorithm development, system simulation, system test. **Larry Riddle, John Murray, Steve Lease**

NUWC, Newport: Torpedo shell finite element modeling. **Don McDowell**

FULLER TECHNOLOGIES INC.: Power flow sensing and calculations, consultant on system design and test. **Chris Fuller, Jerome Couche**

VPT: Amplifier design and fabrication. **Troy Schelling, Dan Sable**

ACCOMPLISHMENTS TO DATE

- CONDUCTED SINGLE CHANNEL, BROADBAND, CLOSED LOOP TEST IN AIR.
  - Demonstrated broadband active control at higher frequencies and broader bandwidths than current SOA.
  - Demonstrated broadband power flow based control at high frequency
  - Demonstrated automatic reconfiguration of the controller
  - Demonstrated the use of numerical modeling to design the smart sleeve system.
  - **All of the above demonstrated on a real torpedo structure**
- DESIGNED AND CONSTRUCTED FULL SCALE SMART SLEEVE SYSTEM.
  - Implemented on fuel tank section of a Mk 48 torpedo
  - Conducted Test Readiness Review June 14.
- INITIATED TESTING OF THE DEMONSTRATION SYSTEM

TECHNOLOGY TRANSFER

- **THE TECHNOLOGY BEING DEVELOPED IN THIS PROGRAM IS BEING TRANSFERRED INTO SEVERAL PROGRAM AREAS.**
  - **NAVY**
    - **Stealth Torpedo**
    - **Multistatic Sonar Active Noise Suppression**
  - **ARMY**
    - **Battlefield Acoustics Self-Noise Cancellation for Unmanned Land Vehicles**
  - **AIR FORCE/BMDO**
    - **Airborne Laser**
    - **Space Based Laser**
  - **NASA/AIR FORCE/NRO**
    - **NGST**
    - **TPF**
    - **Ultra Light Weight Optics**

REQUIREMENTS

- **FREQUENCY AND BAND**
  - 5000 < Freq. > 25,000 Hz (Focus subset of 500<Freq.>40,000 Hz)
  - High Frequency Band, Self noise, Highest Priority (focus of the TRR)
  - Low Frequency Band, Radiated noise, Second Priority
- **AMPLITUDE/ENERGY FLOW**
  - Measured relative to fuel tank section excited, with and without active control. 10 db reduction.
- **AFFORDABILITY**
  - < $30K per system
- **SIZE**
  - Reduce thickness to 2 in. Robust (fault tolerant) and with reduced complexity, maintaining or increasing the level of integration.

SYSTEM CONFIGURATION

PROBLEM STATEMENT: TBL energy from vehicle motion couples to the shell and excites structural vibration energy that flows within the shell walls upstream to the sonar sensor. This vibrational energy raises the noise floor (background) thus limiting the sonar performance.

Reducing this power by an active control system is the prime objective of this program.

The systems configuration developed from problem understanding of

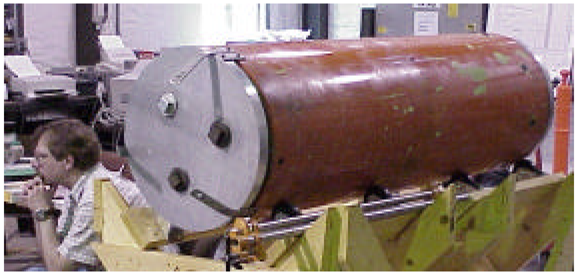
1) Source,
2) Transmission paths,
3) Energy flow
4) Sensing physics and
5) Active cancellation control options

The optimum geometry is a ring or band of actuators (mounted internally) rather than actuators spread over a large area skin (CSM-like). This program is thus called a "Smart Sleeve Demonstration".

FINAL GEOMETRY

The Shell section contains six distinct subsystems,

1) A TBL-like noise source
2) Reference sensors
3) Error sensors
4) Structural actuators
5) Digital control systems
6) Signal monitoring systems



Configuration baseline Mk 48 Fuel Tank Section

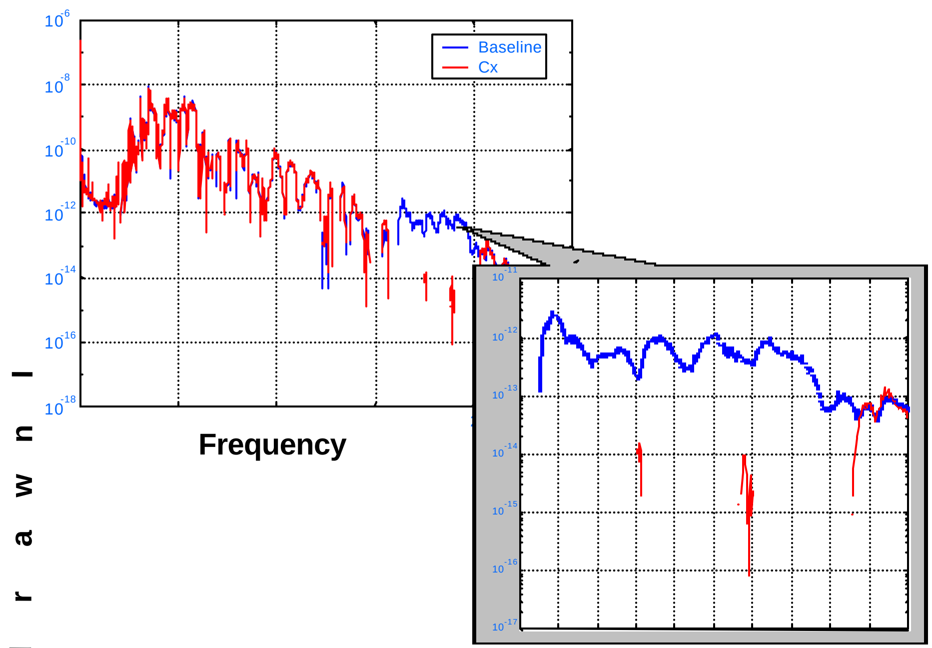
The system configuration was determined from an iterative process of risk reduction that used:

1) flat plate tests, and

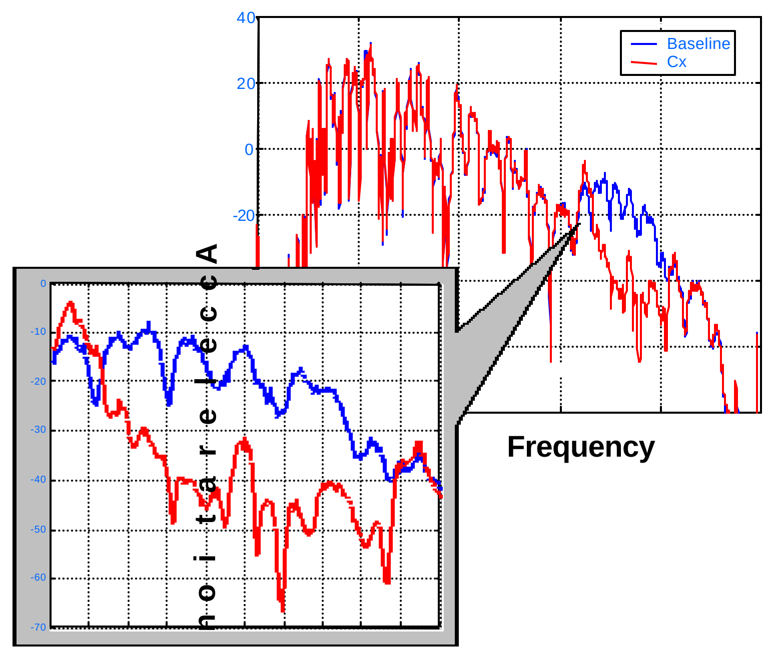
2) In-air tests with one channel of limited operation.

The key driver of the configuration is the the choice of control architecture coupled with an extensive set of structural vibration simulations that defined optimum geometric placement of components.

SMART SLEEVE SINGLE CHANNEL TEST RESULTS 3 KHZ BANDWIDTH POWER FLOW CONTROL



Inward power flow measurement (Regions of net outward flow not plotted)



Real time controller error sensor spectra

Controller uses SW selectable bands to create frequency band windows in the TBL noise. Power flow measurement verifies proper control operation. 18 dB cancellation performance.

SINGLE CHANNEL TEST COMPONENT SUMMARY

S2D Component	Test Result
Sensors	Adequate
Actuators/Amplifiers	Sufficient Authority; Design modifications needed to reduce distortion at Low Frequencies
Preamps	Adequate noise properties; more gain required
Control Hardware	Higher efficiency; 20% slower clock rate
TBL Noise Source	Adequate output; Power amp has 2.5 MHz pulse interference
Control Software	All functions but Decimate ANC work with greater capability than designed.
Power Flow Estimation Software	Performs well

While individual components performed well and their requirements had been specified correctly, more time needs to be spent on system integration to eliminate electronic noise

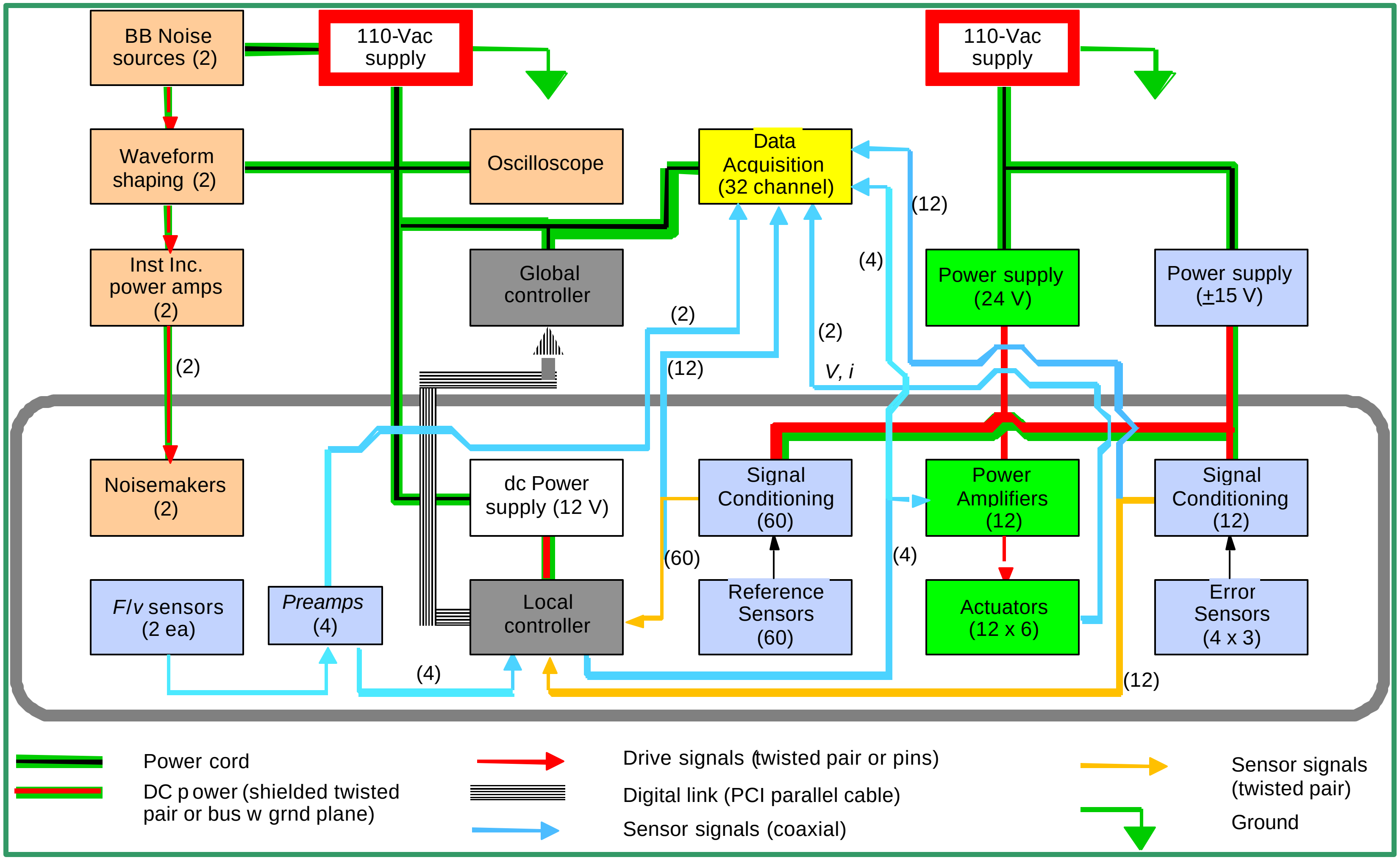
DEMONSTRATION OBJECTIVES

- **VERIFY 10 dB REDUCTION IN SELF NOISE OVER THE BAND OF INTEREST USING THE FUEL SECTION OF A MK. 48 TORPEDO**.
  - Understand the relationship between cancellation performance and performance of system hardware components.
  - Verify accuracy of and usefulness of shell response models
  - Verify algorithm performance.
- **TEST PRODUCTS**
  - Data set adequate to develop into a full scale demonstration.
  - Metrics on performance of MCFXLMS, power flow control, genetic algorithms.
  - Actuator, sensor and amplifier performance metrics
- **CRITICAL QUESTIONS**
  - Can we demonstrate 10 dB reduction over the entire band (2-40 kHz)?
  - What is the effect of cancellation bandwidth on performance?
  - Will cancellation/reduction of self noise be offset by an increase in radiated noise?
  - Can we meet cost and miniaturization goals.

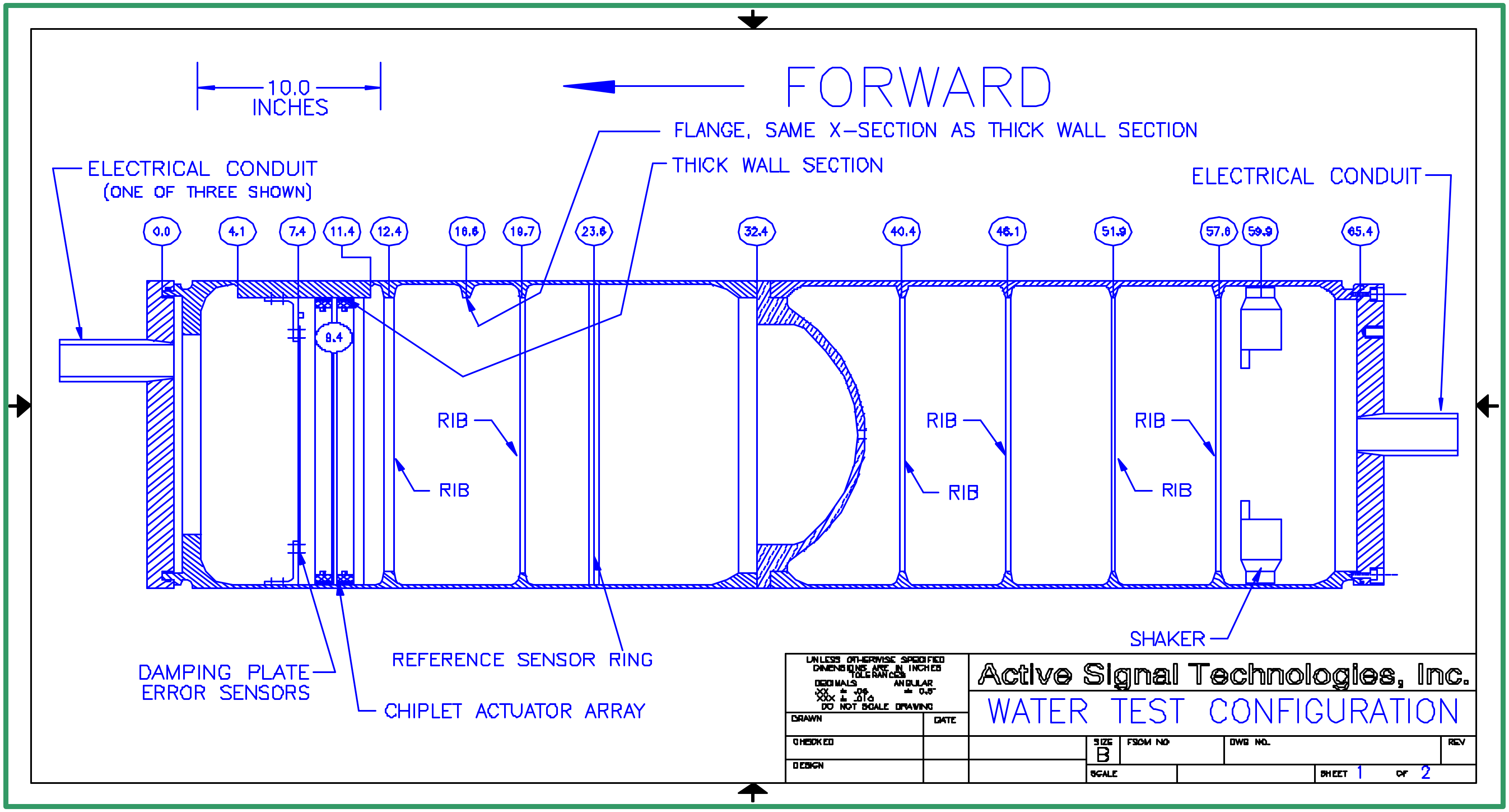
SUCCESS CRITERIA

- **THESE CRITERIA ARE TO BE MET PRIOR TO TEST SHUTDOWN**
  - **Cancellation Performance:**
    - Holy Grail, 10 dB across the band from 2-40 kHz
    - Excellent: 10 dB across the band from 2-25 kHz, with performance decreasing between 25 and 40 kHz.
    - Good: As above, in 6 kHz subbands
    - Minimum Required: 10 dB across the band from 5-25 kHz in 3 kHz subbands.
  - **Automatic reconfiguration of the controller**
  - **Understand contributions to cancellation performance of actuators, sensors, power system and controls hardware and software.**
  - **Evaluate (quantify) performance of MCFXLMS and Power Flow algorithms.**

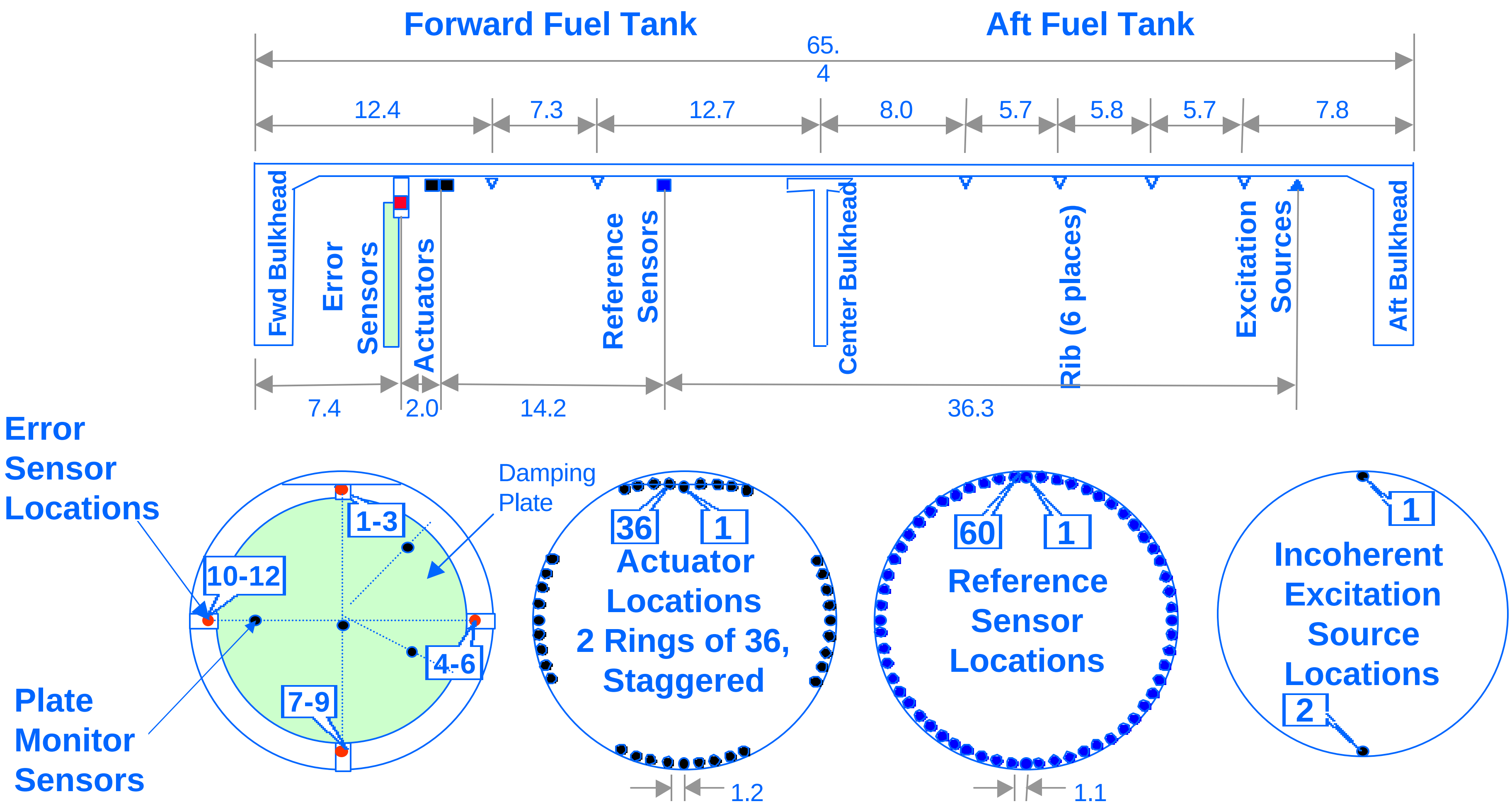
TEST ARTICLE BLOCK DIAGRAM



TEST ARTICLE CONFIGURATION

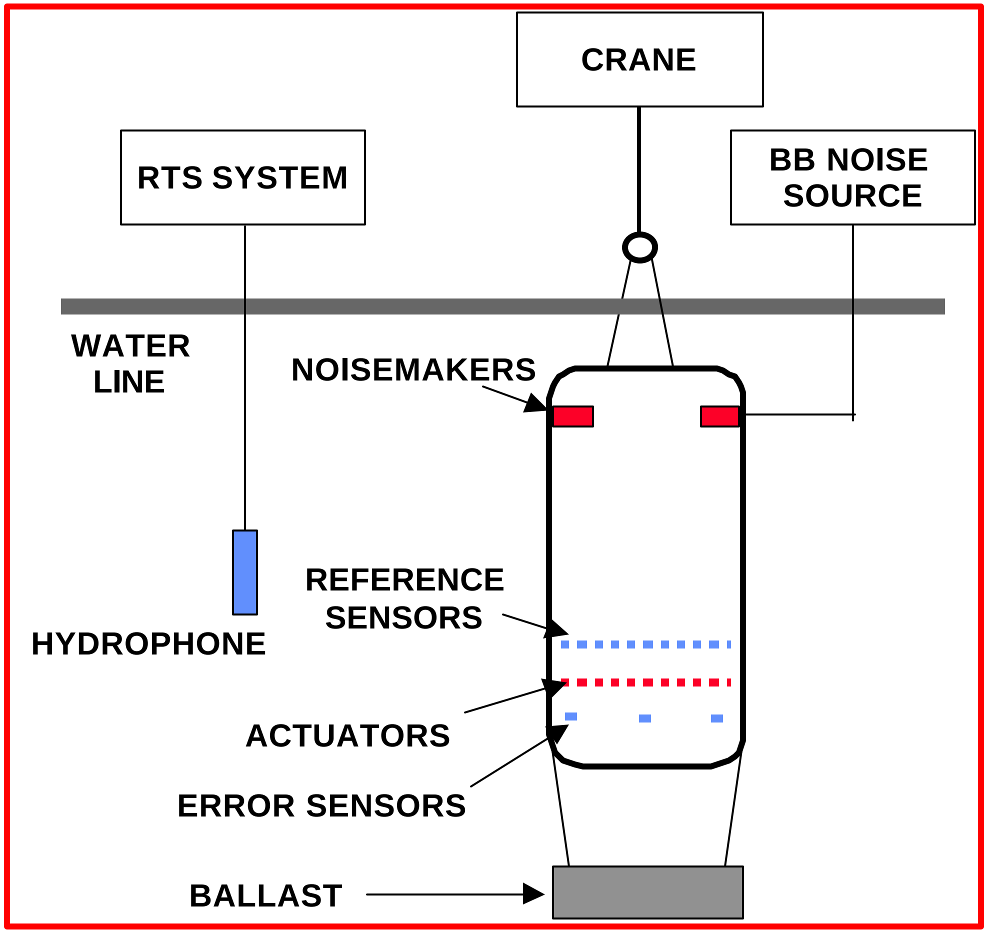


Location of Sleeve Components on Test Article

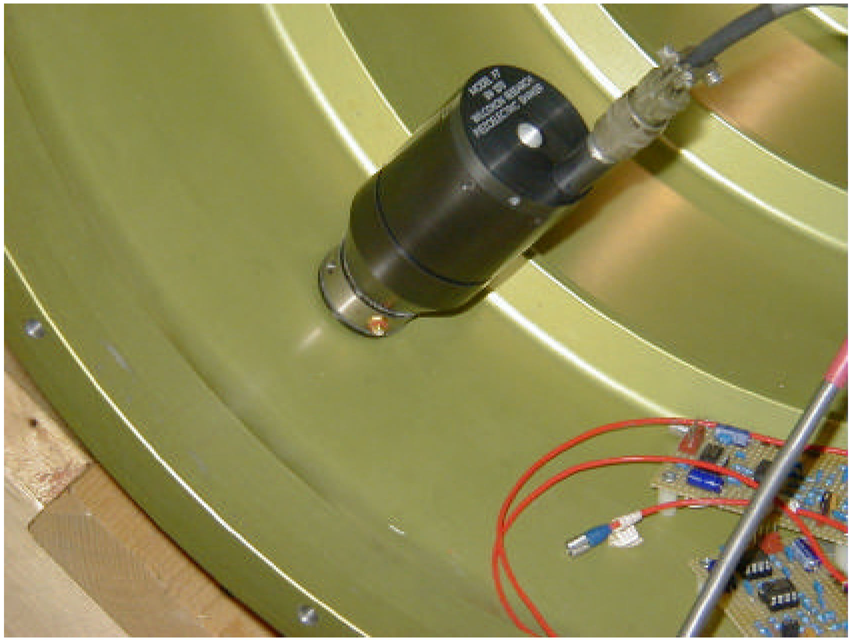


Drawing not to scale, dimensions are in inches.

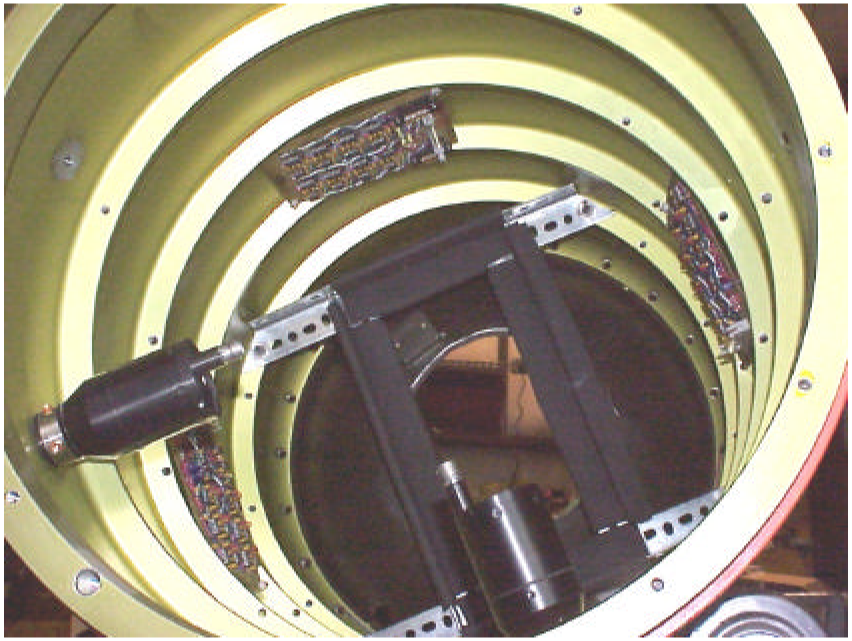
IN WATER TEST CONFIGURATION



TBL SIMULATOR

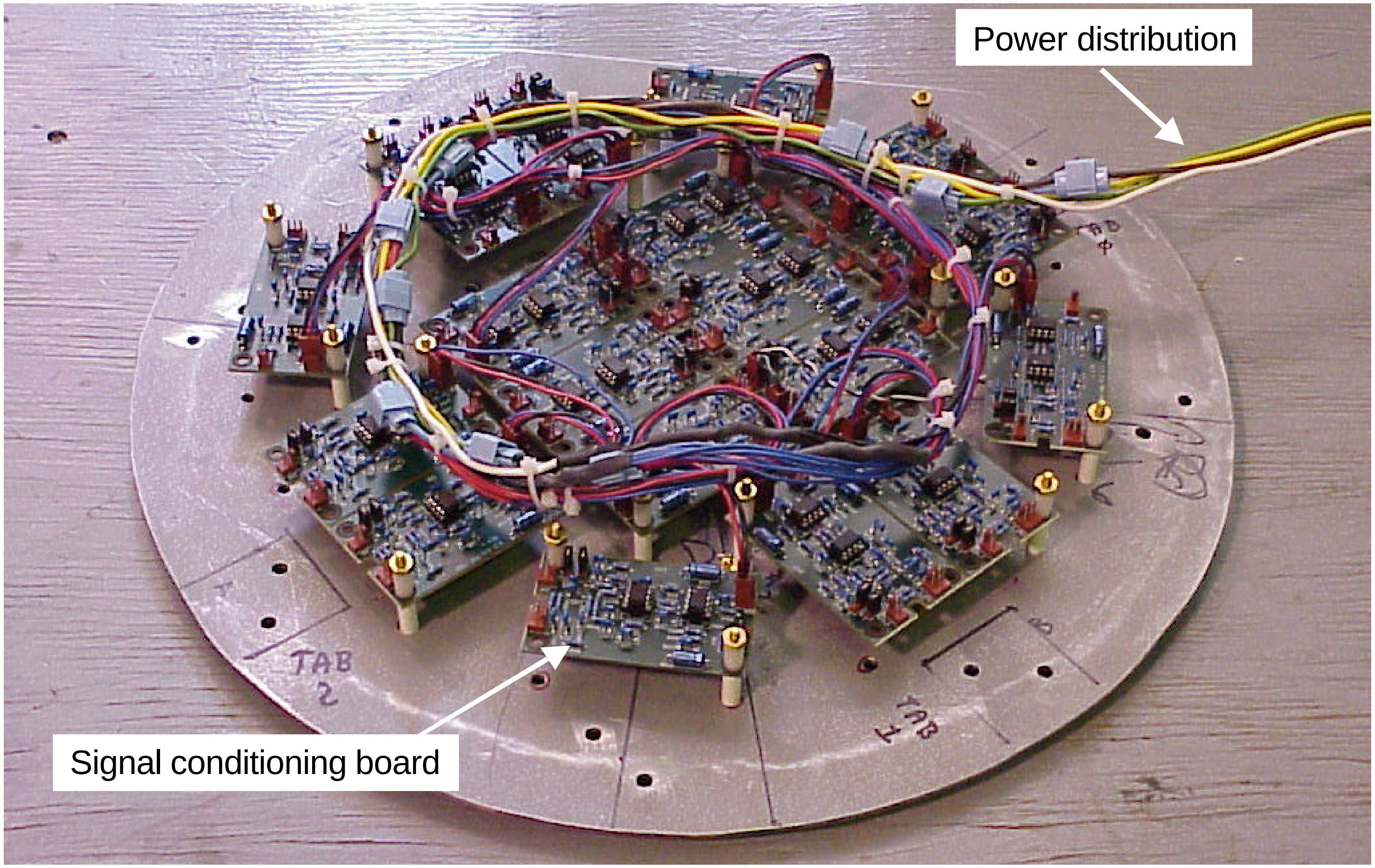


Wilcoxon Actuator

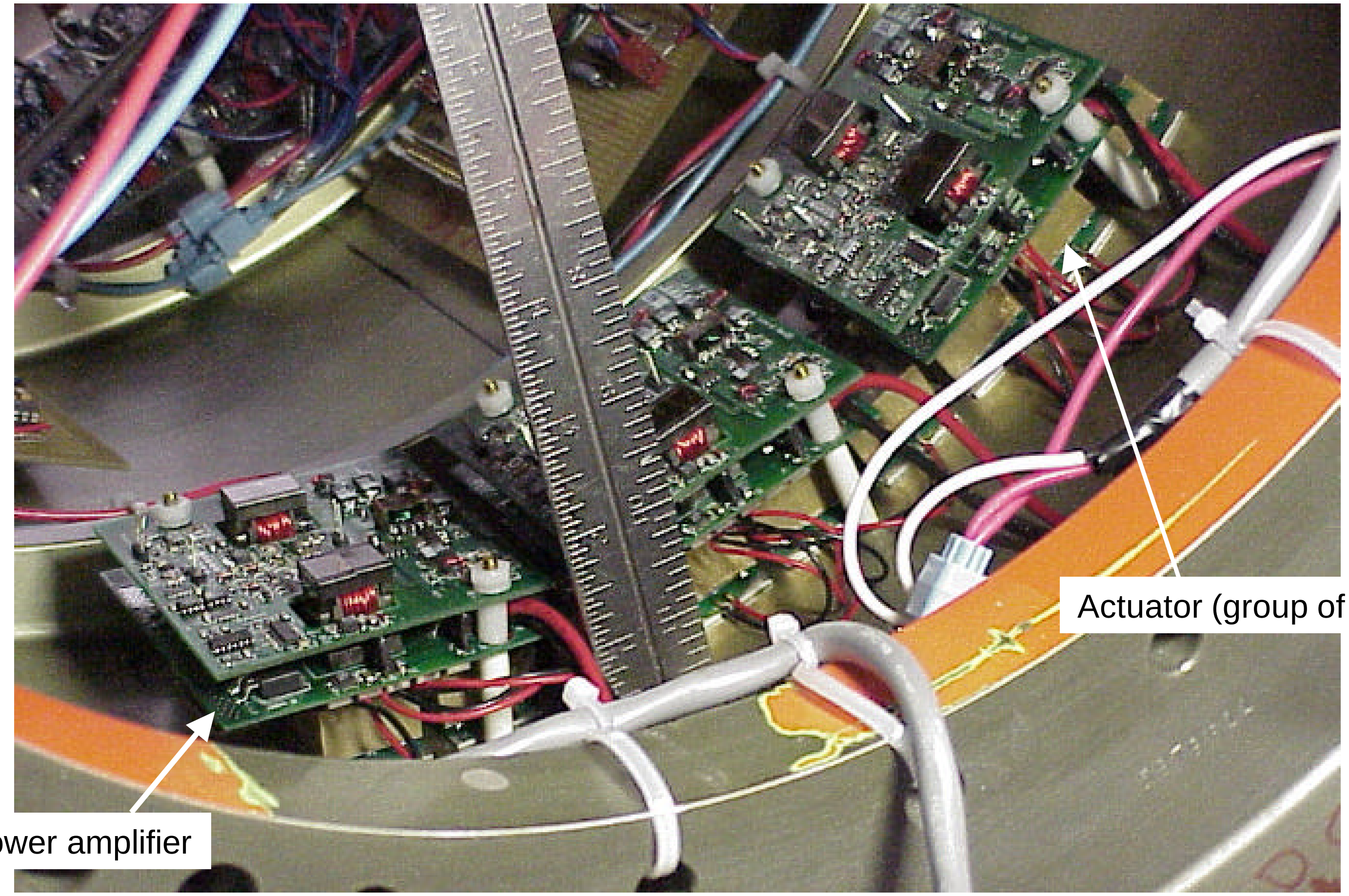


Two Wilcoxon actuators are used to input simulated TBL energy.

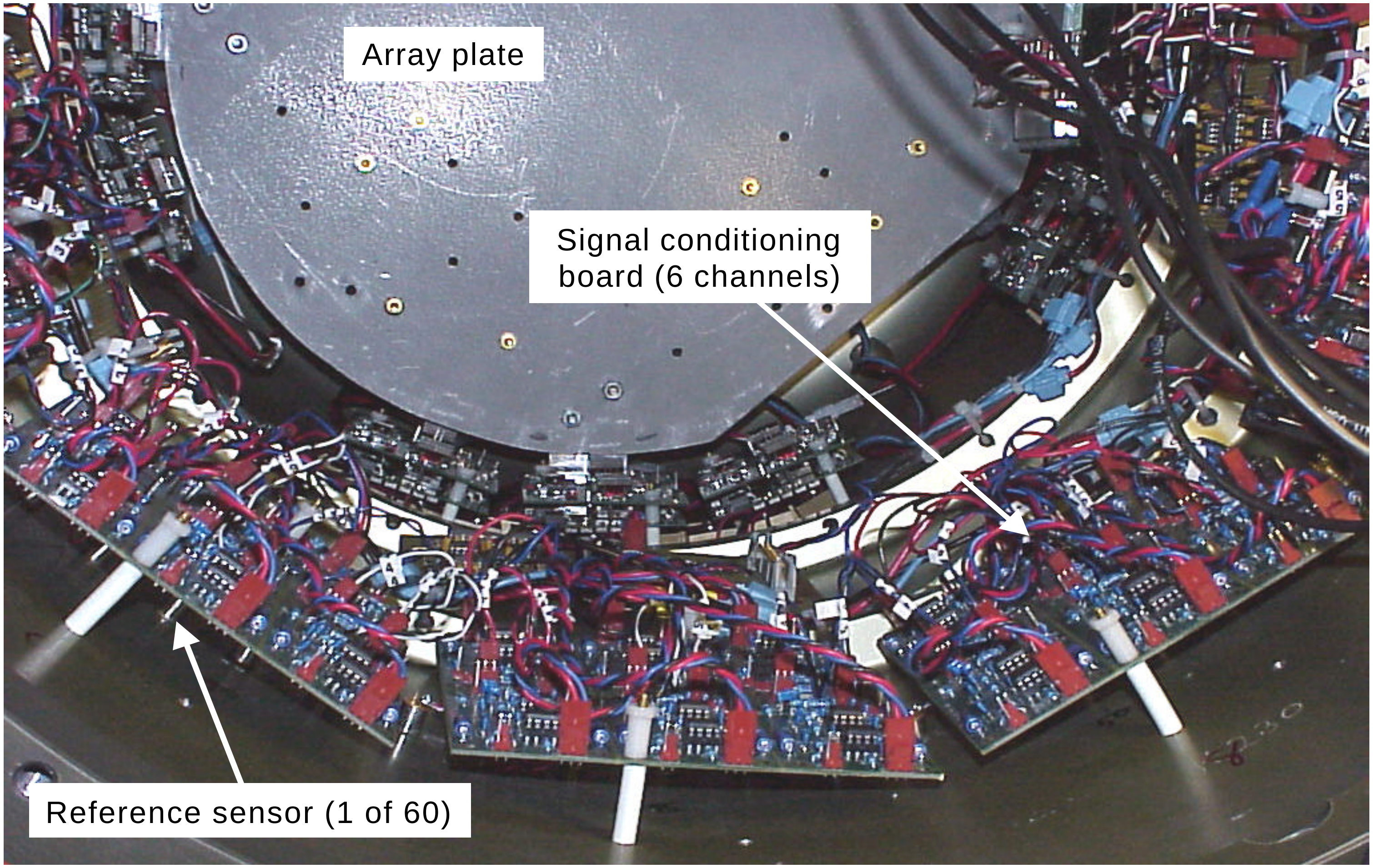
ARRAY PLATE, POWER DISTRIBUTION AND SIGNAL CONDITIONING BOARDS



ACTUATOR AND AMPLIFIER INSTALLATION



SENSORS AND SIGNAL CONDITIONING



CONTROLLER TEST READINESS

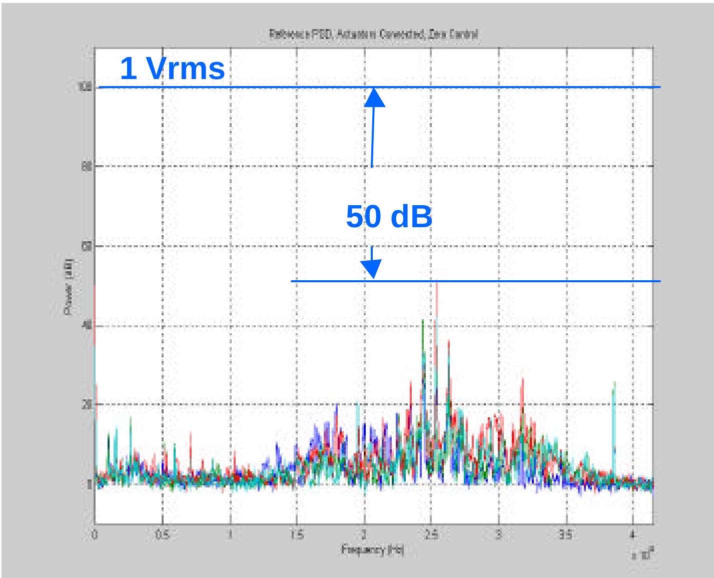
- **Controller is fully functional and runs in real time @ 83 kHz**
- **All controller functions have been tested using air duct test apparatus**
- **High risk interface between controller and sensors has been tested and verified**
- **Reference sensor selection time will be driven by controller convergence on the S2D system**
  - 208 reference selection evaluations needed per frequency band
  - Critical question is whether less than 12 second convergence can be reliably obtained in S2D system and used for reference sensor selection
- **There are no known controller hardware or software problems which would prevent proper testing of the S2D system**

Controller is ready for S2D testing

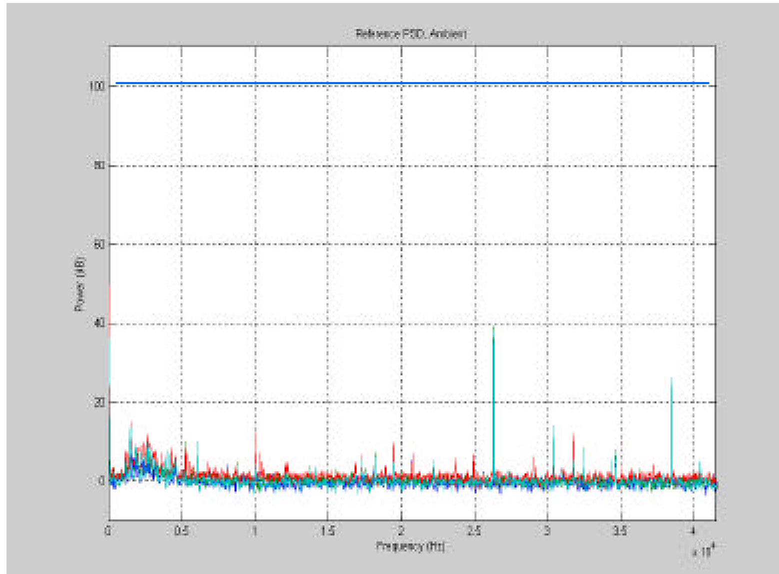
EMI MEASUREMENTS

Accelerometer spectra seen at controller

Amplifiers Powered On

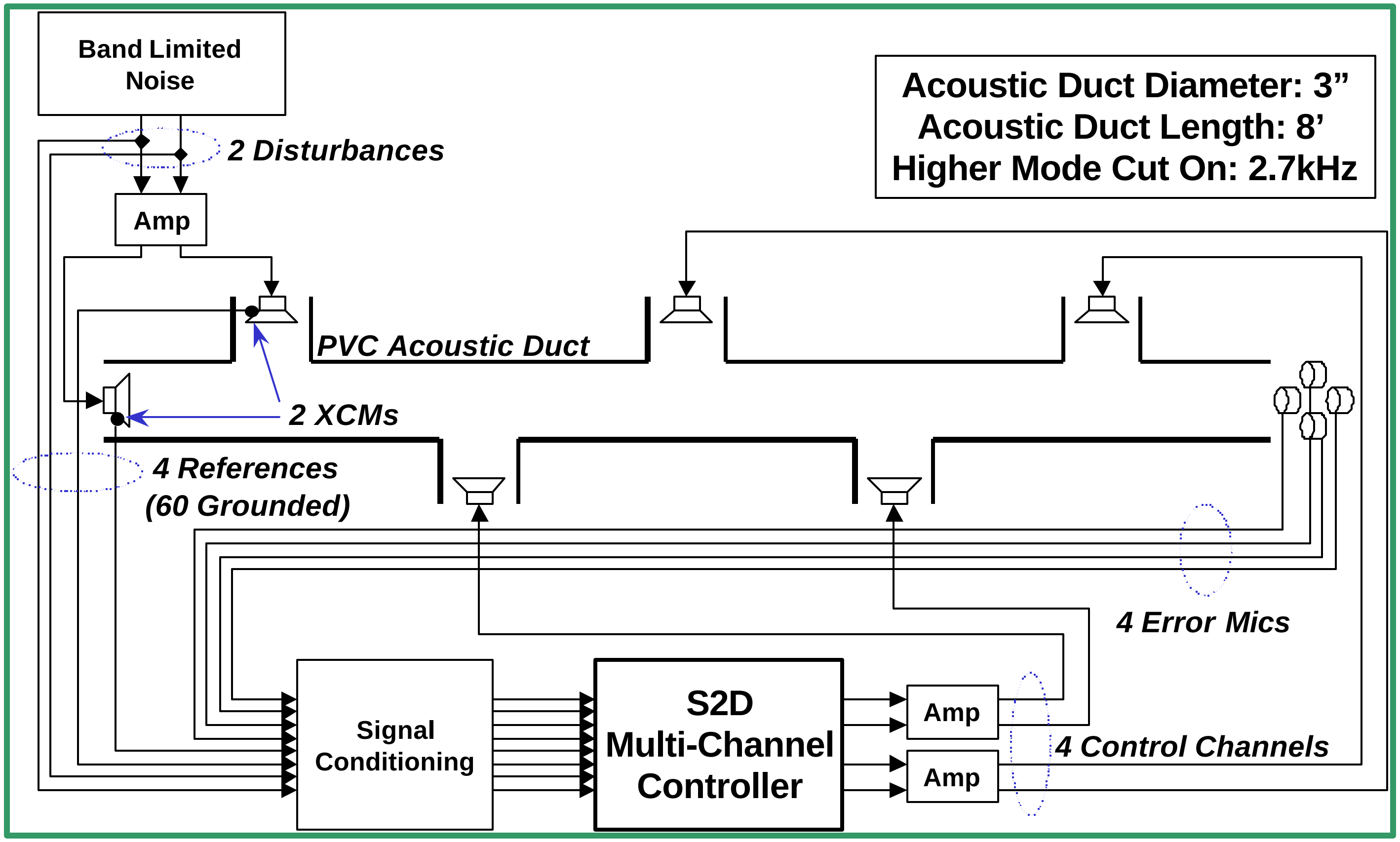


Amplifiers Powered Off



50 dB dynamic range is adequate for active noise control

ACOUSTIC DUCT TEST



Controller function was verified using an acoustic duct test.

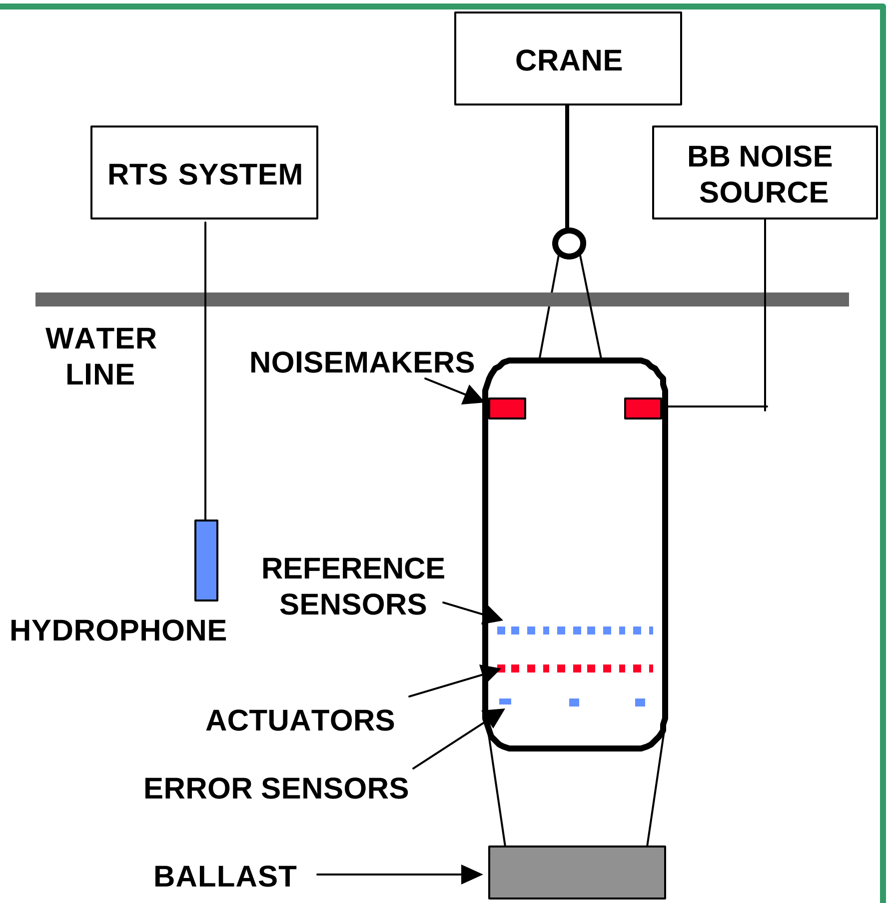
CONTROLLER CLOSED LOOP PERFORMANCE IN AIR DUCT

Frequency Band (Hz)	Cancellation (Power Sum of all 4 error sensors)
2000 - 5000	15 dB
3500 - 6500	12 dB

Controller performance in air duct is limited by tap lengths due to long impulse responses in 8' air duct

ATF HARDWARE STATUS

ITEM	STATUS
Crane	Inspected/repaired Dec 99
RTS System	Operational
Hydrophone	Calibrated Dec 99 (reciprocity)
BB Noise Source	
HP 3562	Operational
Inst Inc. amp.	Operational
Ballast	Ready to be attached



CONCLUSIONS AND REMAINING EFFORT

- **DEMONSTRATION ARTICLE IS COMPLETE AND TESTING HAS BEGUN.**
  - All elements and subsystems have been checked and are ready. Some issues have occurred with the amplifiers, these have been corrected.
  - Testing in air (systems check at levels expected in water) is under way.
  - In water testing will begin July 5.
- **TEST SERIES WILL BE COMPLETED BY THE END OF JULY**
- **FINAL REPORT WILL BE COMPLETED AND SUBMITTED BY SEPTEMBER 30.**
- **FOLLOW-ON PROPOSAL WILL BE COMPLETED BY SEPTEMBER 1**
  - **Follow-on will mark the transition between DARPA-funded and Navy funded program.**
  - **Follow on will depend on performance, especially in the high frequency part of the band.**